Lawrence Livermore National Laboratory

Science & Technology REVIEW

October/November 2010

Livermore Wins 6 R&D 100 Awards

Also in this issue:

Expanding the Periodic Table

Summer Students Engage in Diverse Research

About the Cover

Laboratory researchers captured six R&D 100 awards in *R&D Magazine*'s annual competition for the top 100 industrial innovations worldwide. Highlights beginning on p. 4 describe the award-winning technologies: a high-performance strontium scintillator for gamma-ray spectroscopy, a software application called the statistical radiation detection system, an x-ray free-electron laser energy monitor, a grating-actuated transient optical recorder, ultrapermeable carbon nanotube membranes, and microelectromechanical-systems-based adaptive-optics optical coherence tomography. Since 1978, Livermore researchers have received 135 R&D 100 awards. The R&D 100 logo is reprinted in this issue courtesy of *R&D Magazine.*

Cover design: Amy E. Henke

About *S&TR*

At Lawrence Livermore National Laboratory, we focus on science and technology research to ensure our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published eight times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

The Laboratory is operated by Lawrence Livermore National Security, LLC (LLNS), for the Department of Energy's National Nuclear Security Administration. LLNS is a partnership involving Bechtel National, University of California, Babcock & Wilcox, Washington Division of URS Corporation, and Battelle in affiliation with Texas A&M University. More information about LLNS is available online at www.llnsllc.com.

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National Nuclear Security Administration

Prepared by LLNL under contract
DE-AC52-07NA27344

Science & Technology REVIEW

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S&TR, a Director's Office publication, is produced by the Technical Information Department under the direction of the Office of Planning and Special Studies.

S&TR is available on the Web at str.llnl.gov

Printed in the United States of America

Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

UCRL-TR-52000-10-10/11
Distribution Category UC-99
October/November 2010

Contents

2010 R&D 100 Awards

3 **Shaping the Nation's Future**
Commentary by Thomas F. Gioconda

4 **A Scintillating Radiation Detection Material**
A new scintillator material beats the competition as the superior gamma-ray detector.

6 **Software Solution for Radioactive Contraband Detection**
An innovative software solution rapidly and reliably detects radionuclides when measurement time is short and demand for confidence is high.

8 **Measuring Extremely Bright Pulses of Light**
A new detector can nonintrusively measure a free-electron laser's x-ray energy in real time, pulse by pulse, and with minimal effect on the beam.

10 **High-Speed Imager for Fast, Transient Events at NIF**
A novel instrument can record the fleeting events during the creation of fusion ignition at the National Ignition Facility.

12 **Taking the Salt Out of the Sea**
Carbon nanotube membranes improve water desalination and reclamation processes for increasing Earth's clean water supply.

14 **A Look inside the Living Eye**
Optical coherence tomography gets a boost from adaptive optics and microelectromechanical systems to produce unprecedented images of the retina.

Research Highlights

16 **Collaboration Expands the Periodic Table, One Element at a Time**
A 21-year partnership with a Russian institute has added the six heaviest elements to the periodic table.

20 **Students and Researchers Partner for Summer Projects**
Competitive summer internships pair Livermore researchers with students for hands-on career experience.

Departments

2 The Laboratory in the News

24 Patents and Awards

Molecular Mechanics of a Key Protein

In a paper featured on the cover of the June 16, 2010, issue of *Biophysical Journal*, Livermore scientists Daniel Barsky and Will Kuo, with colleagues from the University of California at Santa Barbara, California Institute of Technology, and University of Cambridge, describe the molecular mechanics of a protein important to all known complex forms of life. The authors conducted molecular-dynamics calculations to reveal the mechanics and dynamics of the eukaryotic sliding clamp proliferating cell nuclear antigen.

Sliding clamps are toroidal proteins that encircle DNA and act as mobile platforms for DNA replication and repair machinery. The calculations reported in the paper are important for understanding the mechanics of DNA replication. The work also shows that large-scale molecular-dynamics simulations, when combined with appropriate coarse-grained elastic models of molecular conformation, can reveal the energy landscape of large conformational changes in proteins.

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Experiment Reveals X-Ray–Atom Interactions

The first user experiment on the Linac Coherent Light Source facility's x-ray free-electron laser (XFEL) at SLAC National Accelerator Laboratory studied the interaction of short-wavelength pulses with single atoms under unprecedented radiation conditions of ultrahigh intensity. Lawrence Livermore is one of the collaborating institutions. The results provide the first experimental evidence for the advantageous radiation hardening effect using ultra-intense x-ray pulses.

"The basic experiment probed our previous purely theoretical understanding of high-intensity x-ray interaction with matter," says Nina Rohringer, a Livermore physicist on the national team. A neon target sequentially ejected electrons during the course of 20- to 100-femtosecond-duration x-ray pulses (a femtosecond is one-quadrillionth of a second). The neon target was completely stripped during the interaction with the XFEL pulse, leaving a bare nucleus.

"Our successful modeling of x-ray–atom interactions using this approach has positive implications for proposed single-molecule-imaging experiments," says Rohringer. The research appeared in the July 1, 2010, edition of *Nature*.

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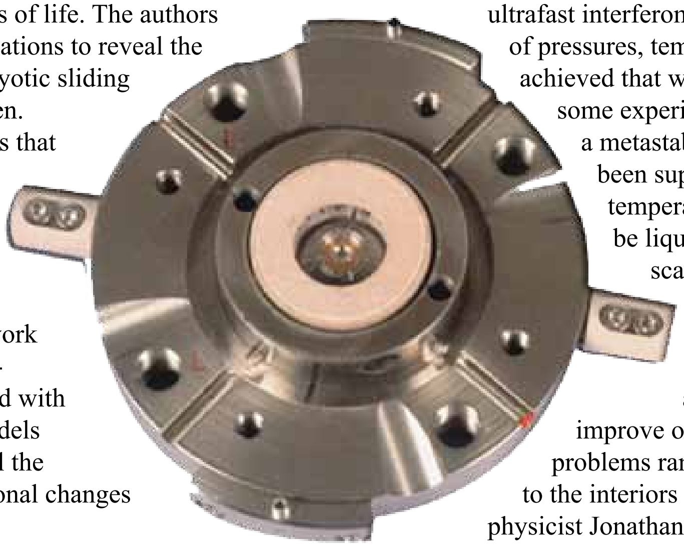
Material Behavior Insight Is a Nanoshock

Laboratory physicists are using an ultrafast laser-based technique, dubbed "nanoshocks," to study shock behavior in tiny samples such as thin films or other systems with microscopic dimensions (a few tens of micrometers). Using a diamond anvil cell (shown below), which probes the behavior of materials under ultrahigh pressures, they statically compressed a sample of argon up to 78,000 atmospheres of pressure (where 1 atmosphere is the pressure at Earth's surface) and then further shock-compressed it to 280,000 atmospheres.



The team analyzed the propagating shock waves using an ultrafast interferometric technique. Combinations of pressures, temperatures, and time scales were achieved that were previously inaccessible. In some experiments, the researchers observed a metastable argon state that may have been superheated—a state of pressure and temperature at which argon normally would be liquid but because of the ultrashort time scale does not have enough time to melt.

"This technique for launching and analyzing nanoshocks can be used to study fundamental physical and chemical processes as well as improve our understanding of a wide range of problems ranging from detonation phenomena to the interiors of planets," says Livermore physicist Jonathan Crowhurst. Results from the team's research appeared in the July 15, 2010, edition of *Journal of Applied Physics*.

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Visualizing How to Turn Plants into Biofuels

A team from Lawrence Livermore led by Michael Thelen, in collaboration with researchers from Lawrence Berkeley National Laboratory and the National Renewable Energy Laboratory, has used four different imaging techniques to systematically drill down deep into the cells of *Zinnia elegans*, a common garden annual plant. The leaves of seedlings provide a rich source of single cells that are dark green with chloroplasts and can be cultured in liquid for several days at a time. During the culturing process, the cells change in shape to resemble tubelike cells that carry water from roots to leaves. Known as xylem, these cells develop the bulk of plant cellulose and lignin, which are both major targets of recent biofuel research.

Using various microscopy methods, the team was able to visualize single cells, cellular substructures, fine-scale organization of the cell wall, and even chemical composition of single zinnia cells. The results go beyond what has been achieved for understanding the architecture of the specialized cell wall that contains such an abundance of lignocellulose. "The basic idea is that cellulose is a polymer of sugars, which if released by enzymes, can be converted into alcohols and other chemicals used in alternative fuel production," says Thelen. The research appeared as the cover article in the September 2010 edition of *Plant Physiology*.

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Commentary by Thomas F. Gioconda

Shaping the Nation's Future

OUR responsibility as a forward-looking laboratory is to shape the nation's future through innovative, multidisciplinary science, technology, and engineering (ST&E). The U.S. faces many pressing challenges in the 21st century that call for the unique expertise and capabilities of the national laboratories. Lawrence Livermore is ensuring the safety, security, and effectiveness of the U.S. nuclear stockpile and pursuing programs to prevent the proliferation of nuclear weapons and counter nuclear terrorism. Our advances in technology are improving military capabilities, strengthening homeland security, and supporting the intelligence community. In addition, we are working to better understand climate change and its impacts, provide for a carbon-emission-free energy future, and keep the U.S. at the forefront of ST&E and competitive in the international marketplace.

The breadth of our mission responsibilities and our innovative application of cutting-edge ST&E are exemplified by the Laboratory's receipt of six R&D 100 awards in 2010—bringing our total to 135 such awards since 1978. These "Oscars of Invention" are presented by *R&D Magazine* to the top 100 technological advances of the year that contribute to meeting an important national or societal need. The six winning technologies developed by Livermore and our many research partners are described in the highlights beginning on p. 4.

National security will be enhanced by two of our R&D 100 Award winners. The statistical radiation detection system (SRaDS) is a novel software solution to rapidly and accurately distinguish nuclear materials, such as plutonium and uranium, from other radioactive substances. SRaDS can easily be integrated into gamma-ray detector systems used for homeland security to search for contraband radioactive materials. A second award was presented for the development of a new material—europium-doped strontium iodide—that will enable high-resolution gamma-ray spectroscopy to be performed by handheld radiation detectors, greatly improving their capability.

The National Ignition Facility (NIF) at Livermore supports our stockpile stewardship mission, offers the prospect of developing carbon-emission-free fusion energy, and provides remarkable capabilities for scientific discovery about our universe. An R&D 100 Award–winning diagnostic system for NIF, the grating actuated transient optical recorder, will enable researchers to acquire sequential images and make a "movie" of a fusion ignition and burn event that lasts only 50-trillionths of a second.

Another Livermore-developed scientific instrument also earned an R&D 100 Award: a system to monitor the energy of pulses generated by x-ray free-electron lasers (XFELs). This instrument is in use at SLAC National Accelerator Laboratory's Linac Coherent Light Source, the world's most powerful XFEL. The light source can capture images of molecules and atoms in motion, making possible many breakthroughs in materials science, biology, and medicine.

In addition, novel prize-winning technologies are meeting important national needs for clean water resources and improved human health. Laboratory scientists developed a filtration technology consisting of carbon nanotube membranes that allow water to flow through about 1,000 times faster than conventional membranes. This capability could provide a more than 80-percent reduction in energy consumption for brackish water desalination. Also, Livermore and other institutions developed a new clinical instrument that permits ophthalmologists to see the eye's retina at the individual cell level. With this capability, doctors will be able to obtain early diagnoses and track the treatment of retinal diseases.

These awards are a tribute to our scientific and technical excellence, our focus on mission, and our workforce's dedication to national service. With my career background as an officer in the U.S. Air Force and a senior manager in the Department of Energy's National Nuclear Security Administration, I greatly value service to the nation and have long recognized it as a value central to the work ethic of the Laboratory. This makes Livermore a special place.

The many researchers featured in the articles describing the R&D 100 awards are to be congratulated for their outstanding work. Their efforts—and those of every Laboratory employee—are shaping the nation's future. That's why we're here.

■ Thomas F. Gioconda is deputy director of Lawrence Livermore National Laboratory.

(a) A crystal of strontium iodide doped with europium for gamma-ray detection is an R&D 100 Award winner. (b) The crystal is encapsulated when used in a radiation detection device and (c) glows blue when exposed to ultraviolet light.

A Scintillating Radiation Detection Material

ENSURING that the country remains safe from a nuclear or radiological attack is driving the search for more definitive radiation detection and identification technologies. The Department of Energy has for decades been building the science and engineering basis for detecting illicit sources of plutonium and uranium. Then, in 2005, the Department of Homeland Security (DHS) made a bold request to develop significantly more effective materials to detect gamma rays. The search began in earnest for new materials for smaller, faster, and more accurate sensors that would improve the nation's ability to unambiguously identify radiation from illicit sources.

Lawrence Livermore and Oak Ridge national laboratories, Fisk University, and Radiation Monitoring Devices, Inc., in Watertown, Massachusetts, joined forces with DHS to develop and optimize new detector materials. Livermore's Steve Payne and Nerine Cherepy are leading the collaboration. "After a lengthy process of scouring the literature and synthesizing and evaluating potential materials, we determined strontium iodide doped with europium to be a winner," says Cherepy. The team has received an R&D 100 Award for their work.

Livermore development team for the strontium iodide scintillator: (from left) Steve Payne, Nerine Cherepy, Owen Drury, Alex Drobshoff, Cheng Saw, Ben Sturm, Thomas Hurst, Scott Fisher, and Peter Thelin.

Improving on the Competition

Detectors made of high-purity germanium, a semiconductor, have long offered the best energy resolution, allowing precise identification of the gamma rays emitted by plutonium and uranium. However, detectors based on germanium require special cooling, making them costly and heavy to use. For field use, radiation detectors must be inexpensive and robust, operate at ambient temperature, provide high detection efficiency, and be small enough for covert operations.

An effective detector must also provide unambiguous identification of a material. Such discrimination is needed because only some gamma-ray energies are indicative of a radiation source that poses a threat. A detector must also pick up very weak signals, such as those from plutonium heavily shielded with lead. Current detector technology is limited in its ability to meet these requirements.

An alternative to semiconductors is scintillators, in which radiation interacts with a material to produce a brief but measurable flash of light. The Livermore-led team hunted for a material that would produce the brightest flash of light when exposed to plutonium or highly enriched uranium. The precision of the scintillator material's response, or energy resolution, defines the material's ability to distinguish between gamma rays that have similar energies.

The most prominent scintillator material in use today is thallium-activated sodium iodide, NaI(Tl), because it is easy to grow in large sizes and is therefore inexpensive. However, its energy resolution is poor compared to semiconductors. Lanthanum bromide doped with cerium offers the highest energy resolution among commercial scintillators, but it is difficult and costly to grow and is inherently radioactive because of the presence of lanthanum-138.

Start from Square One

"DHS recognized the potentially transformational impact that better detector materials could have on our radiation detection capabilities," says Payne. "So the collaboration essentially started by taking out a clean sheet of paper and asking, 'What is possible?'"

They crossed off elements on the periodic table that were not usable because of such properties as optical absorption, radioactivity, or having too low an atomic number to exhibit reasonable gamma absorption efficiency. From the literature, the team assembled a list of prospective materials. They then synthesized small samples of the candidates and evaluated the scintillation properties, eliminating many. Finally, the team created a short list of about two dozen candidates and thoroughly investigated the properties, ultimately identifying strontium iodide doped with europium, SrI_2(Eu), as the material having overall the most useful set of properties.

SrI_2(Eu) can be easily grown, resists cracking, and has no radioactive constituents. The material also exhibits a phenomenon known as better light-yield proportionality. "It turns out," says Payne, "that the fundamental limit to scintillator resolution is dictated by nonproportionality." Proportionality is a direct measure of how much the light yield (divided by electron energy) varies as a function of the electron energy. If a scintillator were perfectly proportional, the relative light yield would be a horizontal line at 1 for all electron energies. No material is perfectly proportional; however, the closer the relationship is to a horizontal line, the better its performance. Compared to existing commercial materials, SrI_2(Eu) hews most closely to this horizontal line.

Putting the Winner to Use

The packaged SrI_2(Eu) scintillator can be easily incorporated into the handheld radiation detectors being produced by many companies and would enhance performance considerably. The Laboratory's Industrial Partnerships Office is in negotiations with several detector suppliers as a replacement for NaI(Tl).

The SrI_2(Eu) scintillator can potentially serve a wide range of applications that use gamma-ray spectroscopy to identify radioisotopes. Isotope identifiers are a common tool for professionals in medicine, police and fire services, and mining operations.

Last year, DHS ordered 20 scintillators, similar to the crystal shown on p. 4, for use in experimental homeland security detection devices. Says Cherepy, "With its poorer energy resolution, thallium-activated sodium iodide cannot pick out the specific gamma rays of plutonium and uranium nearly as well as our award-winning material. Strontium iodide doped with europium offers the best scintillator option yet for detection of potentially devastating radiological materials."

—Katie Walter

Key Words: gamma-ray spectroscopy, R&D 100 Award, radiation detection, radiological attack, strontium iodide scintillator.

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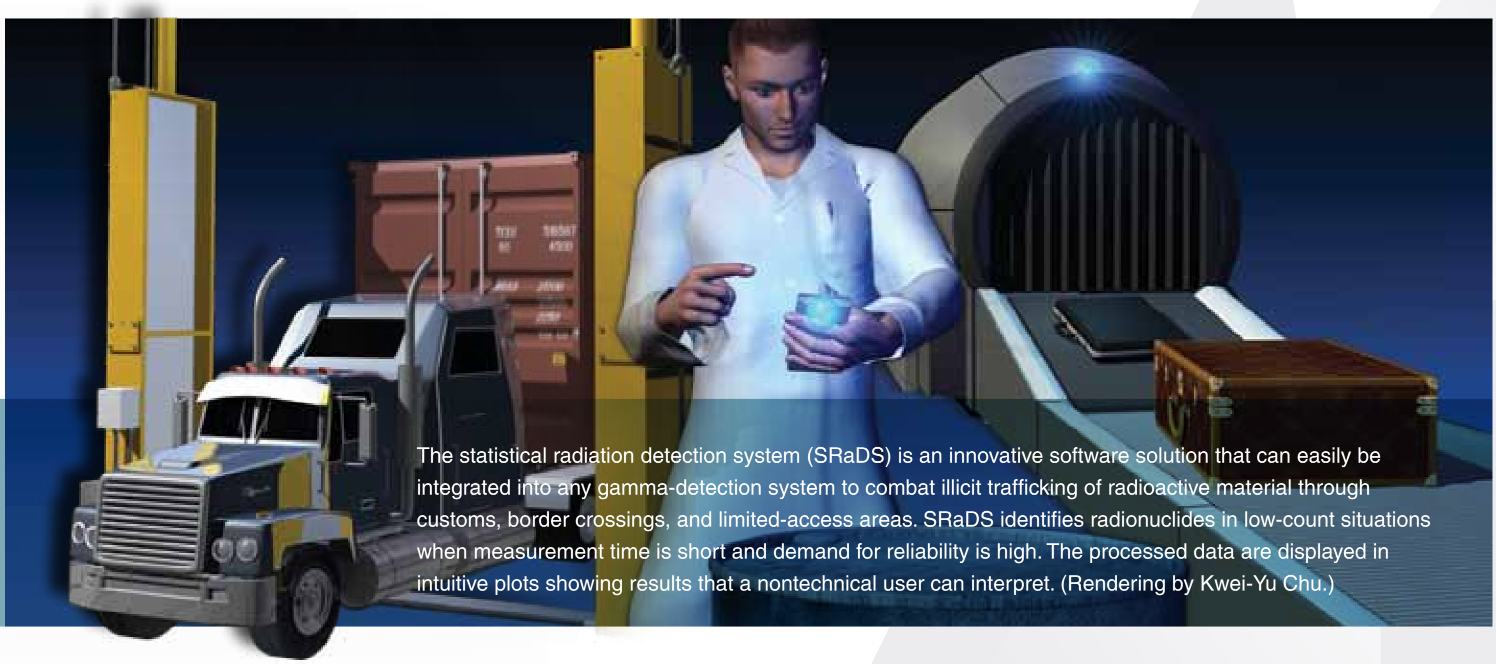

The statistical radiation detection system (SRaDS) is an innovative software solution that can easily be integrated into any gamma-detection system to combat illicit trafficking of radioactive material through customs, border crossings, and limited-access areas. SRaDS identifies radionuclides in low-count situations when measurement time is short and demand for reliability is high. The processed data are displayed in intuitive plots showing results that a nontechnical user can interpret. (Rendering by Kwei-Yu Chu.)

Software Solution for Radioactive Contraband Detection

EACH year, some 48 million cargo containers move among the world's transportation portals with more than 16 million containers arriving in the U.S. by ship, truck, and rail. Illicit radioactive materials could be hidden in any one of these cargo-filled containers. Yet, physically searching every container would bring shipping to a halt. Improving security at U.S. transportation portals is thus one of the nation's most difficult technical and practical challenges because the systems developed for screening cargo must operate in real time without disrupting legitimate commercial shipping activities.

Working at this intersection of commerce and national security, a team of Livermore scientists and engineers led by principal investigator James Candy applied its expertise in radiation science and gamma detection to develop the statistical radiation detection system (SRaDS), an innovative software solution that nonexperts can use to rapidly and reliably detect radionuclides. The team, along with ICx® Technologies, Inc., in Arlington, Virginia, has won an R&D 100 Award for the technology. According to Candy, who derived early support from Livermore's Laboratory Directed Research and Development Program, "the team cross-fertilized the areas of statistical signal processing with radiation transport physics, enabling a unique and breakthrough solution to a long-troubling problem, especially in today's climate of terrorist threats."

Development team for SRaDS: (from left) Brian Guidry, Kenneth Sale, Michael Axelrod, Thomas Gosnell, James Candy, Sean Walston, David Chambers, Eric Breitfeller. (Not shown: Dennis Slaughter, Jerome Verbeke, and Stanley Prussin [UCB].)

Rapid and Reliable Radionuclide Detection

Identifying radioactive material in a moving target is a difficult problem primarily because of the very low counts of gamma-ray signals during the short time interval for detection. In low-count situations such as these, conventional spectrometry techniques do not have enough time to collect the number of protons required to calculate the pulse-height spectra that identify radioactive materials. For example, a vehicle moving through a gamma-detection system at a transportation portal is screened for less than 10 seconds. Accurate radionuclide detection is even more difficult when radioactive material is shielded by lead, packaging, or adjacent cargo.

SRaDS speeds up identification by automatically rejecting extraneous and nontargeted photons during the process. Exploiting Bayesian algorithms, the smart processor examines each photon—one by one—as it arrives and then "decides" whether a detected radionuclide is present based on selected parameters. This capability is not available in conventional detection systems, yet it is essential in the successful identification of radionuclides in low-count situations when measurement time is short and demand for reliability is high.

When a cargo container arrives at an SRaDS detector, a decision function in the software is refreshed, updated, and refined based on the energies and arrival times of the accepted photons. Detection is declared only when statistically justified according to three factors—the Bayesian algorithms, the updated decision function, and the conditions defined by the specific receiver-operating characteristic curve obtained during initial calibration. In contrast, conventional techniques require manually setting a specific counting time in advance with the hope that the data acquired can justify the decision. By encompassing the statistical nature of radiation transport physics and sequential Bayesian processing techniques, SRaDS provides highly developed quantitative statistical analysis of the data received in real time.

What's more, basic and advanced processor options are available with SRaDS. Both processor options provide complete statistical analysis of radionuclide data obtained from any type of gamma detector. The basic and advanced processors gather information from unscattered photons that deposit full photon energy. The advanced processor also gathers information from Compton-scattered photons that exhibit diminished energy—a major breakthrough in time-domain low-count detection technology.

Integrates into Any Gamma-Detector System

The Livermore team took special care to ensure that SRaDS can easily be integrated into any gamma-detection system, including large stationary detectors at transportation portals that help search for contraband radioactive material in moving vehicles, cargo containers, and railroad cars. SRaDS works equally well in pedestrian monitors used to combat illicit trafficking of radioactive material through customs, border crossings, and limited-access areas. The technology can also be installed in portable gamma detectors used by first responders to determine radiation risks associated with local nuclear emergencies. The algorithms are easily embedded in programmable gate arrays that users can adjust in the field to a location's specifications and detection requirements.

Depending on the hardware setup, the processed data can be graphically displayed on a computer monitor or portable unit. While conventional gamma-detection systems require a highly trained practitioner to analyze the results, refine the data, and guide the interpretation procedure, SRaDS displays data in intuitive plots showing results that a nontechnical user can interpret. Alternatively, SRaDS can be configured to simply provide audio and visual alerts indicating the presence of targeted radionuclides at user-selected confidence levels. Users can also select false-alarm probabilities to reduce or eliminate the occurrence of false positives depending on the level of detection required for a given situation.

The result is a comprehensive software system that combines outstanding radionuclide-detection performance with high reliability and a short acquisition time. SRaDS can easily be implemented in existing infrastructure to protect the nation from the insidious threat of illicit radioactive materials.

—Geri Freitas

Key Words: Bayesian processing techniques, cargo container, gamma detector, R&D 100 Award, radionuclide detection, statistical radiation detection system (SRaDS).

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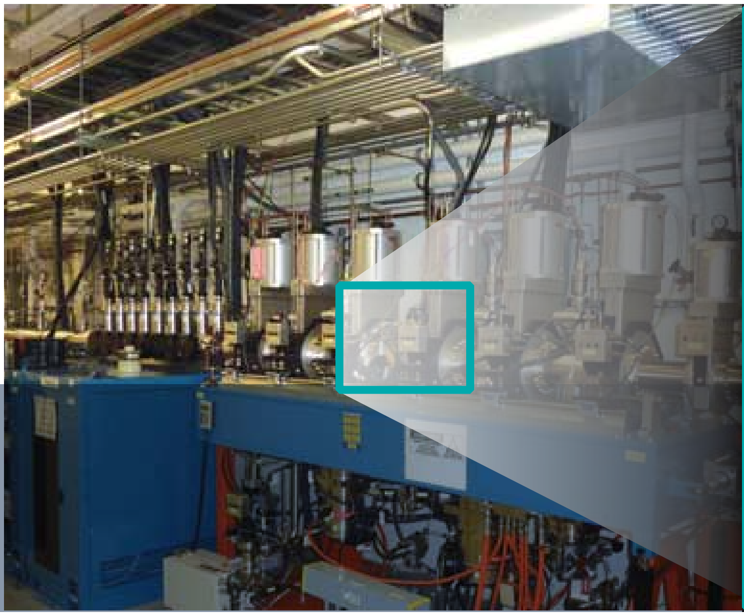

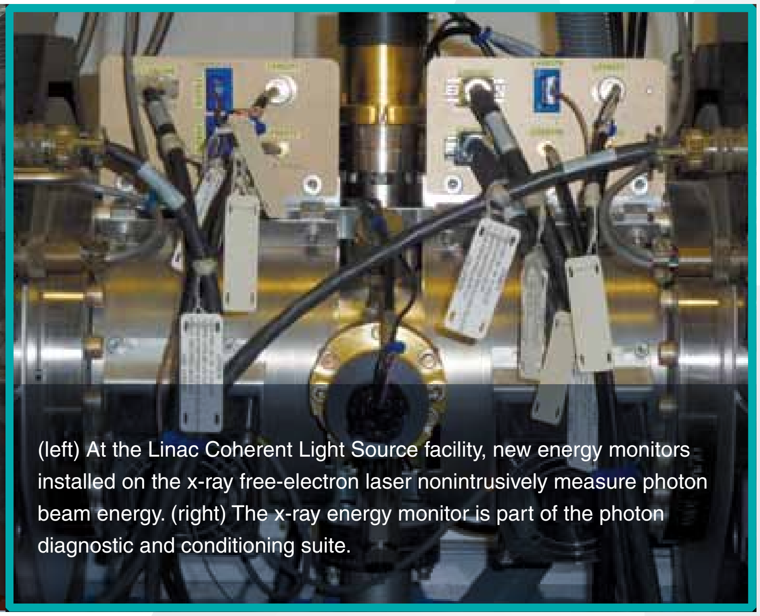

(left) At the Linac Coherent Light Source facility, new energy monitors installed on the x-ray free-electron laser nonintrusively measure photon beam energy. (right) The x-ray energy monitor is part of the photon diagnostic and conditioning suite.

Measuring Extremely Bright Pulses of Light

X-RAY free-electron lasers (XFELs) are tunable, high-power sources of short photon pulses. These new machines offer significant promise for scientific and medical breakthroughs by capturing the motion of molecules and even atoms. The intense pulses generated by XFELs are beginning to enhance time-resolved research in biology, chemistry, materials science, and physics. Designing diagnostic instruments for x rays is challenging, particularly for high-energy pulses, because the x-ray beam can damage the equipment.

In collaboration with SLAC National Accelerator Laboratory in Stanford, California, Lawrence Livermore scientists won an R&D 100 Award for developing a detector, called the XFEL energy monitor, that measures this pulse-by-pulse energy in real time without being damaged by the beam and with minimal effect on beam quality. The team probed nitrogen gas at x-ray energies up to 8 kiloelectronvolts, and the photoluminescence-based pulse-energy detector provided the required calibration information for the team to study the interaction. Nitrogen gas was chosen for the experiments because it is nonhazardous and its ultraviolet luminescence behavior is well understood from use in previous studies to detect and characterize cosmic rays.

Energy monitor development team: (from left) Donn McMahon, Mark McKernan, Richard Kemptner, Dmitri Ryutov, Richard Bionta, Daniel Behne, Keith Kishiyama, Stefan Hau-Riege, Vasco daCosta, Marty Roeben, and Robert Geer. (Not shown: Elden Ables, Stewart Shen [now retired], Alan Wootton [formerly of Livermore], Jacek Krzywinski [SLAC], and Marc Messerschmidt [SLAC]).

Three XFEL energy monitors are currently in use at SLAC's Linac Coherent Light Source facility. In operation since April 2009, this light source is the world's first hard XFEL, capable of generating x rays with wavelengths comparable to atomic distances. It is also the first XFEL available for scientific research, providing users with virtually instantaneous pulse-energy data. During the next few years, XFEL facilities in Japan, Germany, Italy, Switzerland, and England are scheduled to come online.

Revealing the Unseen

X rays are useful for examining all kinds of matter, from DNA, bones, and lungs to the materials comprising stars. If x rays are sufficiently intense and produced in ultrashort pulses, they can reveal information about dynamic processes in many states of matter, such as solid, liquid crystal, and extremely dense plasma. These pulses are much like flashes from a high-speed strobe light, enabling scientists to take stop-motion pictures of atoms and molecules. XFEL pulses allow researchers to measure extremely fast physical events with atomic resolution. The technology can be applied to study regimes for the first time in a vast range of fields including ultrahigh-energy-density physics, structural biology, fundamental quantum electrodynamics, warm dense matter, and atomic physics.

An XFEL's beam pulse lasts less than 100 femtoseconds (a femtosecond is one-quadrillionth of a second), and its beam wavelength measures just about 0.1 nanometers (about the diameter of the smallest atom). The laser's peak brightness—up to a few gigawatts—is billions of times larger than that generated by synchrotrons, formerly the brightest light sources. "The revolutionary output characteristics of an XFEL propels us into a completely new regime of x-ray–matter interaction," says Livermore physicist Stefan Hau-Riege, who headed the detector development team.

Instrument Is Not Intrusive

According to Hau-Riege, studying how matter interacts with x rays requires continuous, detailed characterization of the ultrahigh-intensity photon beam, with minimal intrusion. Knowledge of beam parameters such as photon flux (the number of photons arriving at a point) is essential because the parameters determine how the beam interacts with the experimental sample. However, ascertaining XFEL beam characteristics is particularly challenging because the beam can easily saturate or even destroy commonly used solid-state detectors. The XFEL energy monitor, which barely disturbs the intensity of the x-ray beam, preserves beam coherence and can be operated in a regime in which the attenuation is less than 1 percent.

The total pulse energy is inferred from ultraviolet radiation generated by the nitrogen gas contained in the vessel through which the beam travels. When the beam traverses the vessel, the nitrogen is excited and emits fluorescent radiation that is detected by the energy monitor's photon-multiplier tubes. The nitrogen gas is continuously replenished and maintained at a constant pressure by a series of pumps. Hau-Riege says the interaction of hard x-ray photons with nitrogen is small, and if necessary, the nitrogen gas density can be decreased during operation.

A Bright Future

Although the energy monitor was developed primarily for characterizing ultrahigh-brightness x-ray pulses from hard XFEL facilities, it may also be used to characterize less bright x-ray sources. In fact, the team successfully tested a prototype of the device at the Stanford Synchrotron Radiation Light Source, which generates x-ray beams with intensities billions of times weaker than the Linac Coherent Light Source.

A research paper describing the XFEL energy monitor appeared in the July 23, 2010, edition of *Physical Review Letters*. The paper was co-authored by the Livermore researchers, together with colleagues from SLAC and the Center for Free-Electron Laser Science in Hamburg, Germany. The paper has helped to communicate to the physics community that the most energetic x-ray beams ever produced can be well characterized.

—Arnie Heller

Key Words: Linac Coherent Light Source, R&D 100 Award, SLAC National Accelerator Laboratory, x-ray free-electron laser (XFEL) energy monitor.

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The grating-actuated transient optical recorder (GATOR) is designed to acquire sequential images of x rays or optical light in a trillionth of a second or faster during experiments on the National Ignition Facility.

High-Speed Imager for Fast, Transient Events at NIF

FUSION ignition experiments at the National Ignition Facility (NIF), the only laboratory in the world capable of re-creating the extreme temperatures and pressures found in stars and in thermonuclear weapons, will last only a few billionths of a second. An actual fusion "event," when a capsule filled with tritium and deuterium—isotopes of hydrogen—undergoes ignition and thermonuclear burn, occurs in just trillionths of a second, much too quickly for traditional diagnostic and imaging equipment to record.

For the National Ignition Campaign to reach its goals of advancing understanding of plasma physics and helping to certify the reliability and safety of the nation's aging nuclear stockpile, a new generation of ultrafast, high-resolution diagnostic equipment must record events in picoseconds (trillionths of a second). To meet that need, Livermore physicists developed the grating-actuated transient optical recorder (GATOR), which won an R&D 100 Award. This optical instrument is designed to capture and record fleeting, sequential images of x rays and other radiation emitted from the miniature "stars" created in the NIF target chamber.

A New Concept to Record Ignition

An entirely new concept for high-speed imaging, GATOR encodes two-dimensional x-ray or optical images onto coherent light. Its design is derived from a 2009 Laboratory Directed Research and Development project on probing extreme high-energy-density states of matter with x rays. The instrument can provide the necessary time resolution in picoseconds to record x-ray or optical images of NIF's ignition events, enabling scientists to better understand the physical processes occurring in these experiments. Because the radiation conversion process is done optically, GATOR does not use charged particles and thus does not suffer from the fundamental space-charge limitations of commercial electro-optical systems, which can restrict a system's speed, spatial resolution, and dynamic range.

In addition, because GATOR can convert x rays and other types of radiation to coherent optical radiation, which can be transported and recorded remotely, the instrument can operate in an environment

in which copious amounts of neutrons, x rays, and gamma rays are released during ignition experiments. These radiation levels would almost certainly disable or destroy conventional detectors installed near an igniting capsule.

Creating Ignition at NIF

The extreme temperatures and pressures occurring during NIF ignition and burn—predicted by simulations to last for only 50-trillionths of a second—create enormous challenges for diagnostic instruments. During that time, conditions change rapidly, with the capsule emitting x rays, gamma rays, and neutrons. Two-dimensional images with a spatial resolution of about five-thousandths of a millimeter and a time resolution of about five-trillionths of a second are needed to measure the detailed physical processes. The instrument must achieve this performance without being affected by hard-to-shield neutrons and gamma rays or the electromagnetic pulse they generate. The GATOR diagnostic can record a sequence of images with picosecond time resolution, enabling researchers to measure these fast transient phenomena.

The GATOR diagnostic system has four elements: a grating, a specially prepared semiconductor, a probe laser, and a recording system. Radiation from an external source (in this case, the ignition event) strikes a grating or mask containing a series of thin bars that block some of the light. This pattern of light is then focused on a specially treated semiconductor, where it is absorbed. The absorbed light modifies the optical properties of the semiconductor in proportion to the intensity of the illumination. A probe laser beam striking the rear surface and reflecting off the front surface of the semiconductor passes through the optically modified semiconductor twice, diffracting a portion of the beam away from its original path. The focused pattern of the diffracted beam is a series of spots, one for each diffraction angle, arrayed symmetrically around the undiffracted part of the probe beam. The diffracted portion of the beam is relayed by a lens system and focused to form high-resolution images of the incident radiation on a charge-coupled-device detector located at a distance and heavily shielded from the experiment's high-energy background radiation.

Because the duration of the recording is determined by the duration of the applied laser beam, GATOR can acquire sequential images, capturing temporal changes in the target in a small "movie" of the fleeting event. The instrument converts the source radiation to optical images before slower-moving neutrons, charged particles, or debris can reach the semiconductor. Because GATOR is an all-optical device, no electronics or cables need to be located near the x-ray source, helping make the system much less vulnerable to the potentially destructive effects of radiation and electromagnetic-pulse fields. Livermore calculations show that the instrument can produce useful images in environments with neutron yields greater than 20 megajoules.

A flexible system, GATOR can be adopted for any application in which very fast, high-power energy sources are used or created, including high-power lasers, free-electron x-ray lasers, and high-energy-density objects. GATOR will allow detailed measurements to be taken of the ignition conditions involved in studying the high-energy-density physics of thermonuclear burn, advancing scientific understanding of stars and furthering stockpile stewardship.

—Arnie Heller

The GATOR development team: (from left) Steve Vernon, Rick Stewart, Warren Hsing, Mark Lowry, and Paul Steele. (Not shown: Susan Haynes.)

Key Words: electromagnetic pulse, fusion, grating-actuated transient optical recorder (GATOR), National Ignition Campaign, National Ignition Facility (NIF), R&D 100 Award.

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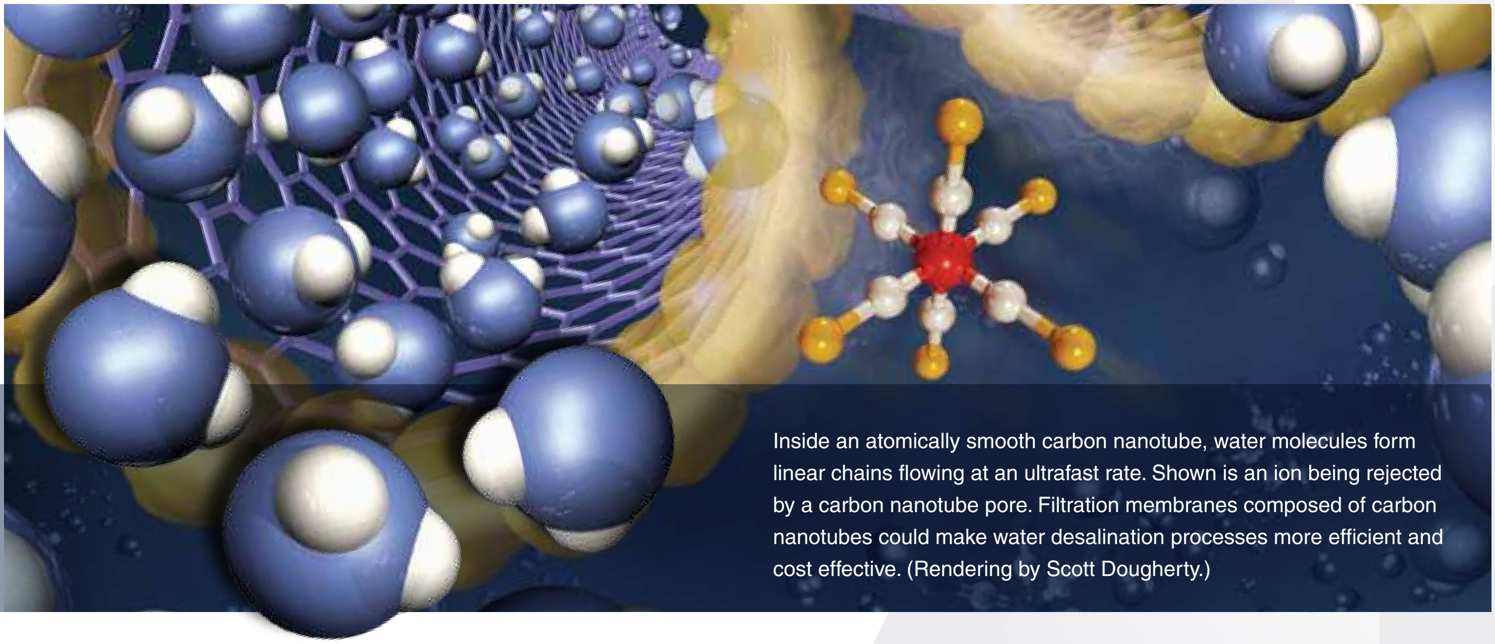

Inside an atomically smooth carbon nanotube, water molecules form linear chains flowing at an ultrafast rate. Shown is an ion being rejected by a carbon nanotube pore. Filtration membranes composed of carbon nanotubes could make water desalination processes more efficient and cost effective. (Rendering by Scott Dougherty.)

Taking the Salt Out of the Sea

WATER is a precious natural resource and one of the basic building blocks of life. Yet, according to UNICEF, nearly one in six people worldwide lacks access to clean drinking water. In some areas, water scarcity has resulted in conflict between neighboring states. As demand for this resource continues to increase globally, finding ways to make more of Earth's water—97 percent of which is seawater—fit for human consumption will be of great importance in creating an adequate clean water supply for the billions of people worldwide.

A novel R&D Award–winning membrane technology developed by Lawrence Livermore in partnership with Porifera, Inc., in Hayward, California, and with early support from Livermore's Laboratory Directed Research and Development Program, could lead to more cost-effective filtration processes for water desalination and reclamation than are available today. The highly permeable, chemically inert membranes are composed of carbon nanotubes (CNTs), which are hollow, seamless cylinders. Extremely smooth interior walls allow liquids and gases to rapidly flow through CNTs, while rejecting larger molecules.

Because of a CNT membrane's sophisticated structure and material properties, solutes such as salt and other ionic compounds can be filtered out of seawater or brackish water using substantially less energy than is needed to achieve similar results with conventional polymer-based membranes. Although the high energy costs and relatively low efficiencies of standard water filtration processes have hindered development of large-scale desalination facilities in the past, CNT membranes could help make such facilities a widespread reality.

Molecules Go with the Flow

Billions of carbon nanotubes, each one about 50,000 times thinner than a human hair, are grown on a single silicon substrate using chemical vapor deposition. (See *S&TR*, January/February 2007, pp. 19–20.) The space between this "forest" of nanotubes is then filled with a matrix material such as silicon nitride to create the membrane. Excess material is removed from either end, and the top and bottom of the nanotubes are reopened using a reactive ion-etching process.

"The primary advantage to CNT membranes is that water flows through them at a rate 1,000 times faster than through the polymer-based membranes typically used in water filtration equipment," says former Livermore scientist Jason Holt. This fast transport is made possible because of the unique properties of a CNT's inner surface, which is atomically smooth, hydrophobic, and nonpolar with a uniform distribution of electrons. As a result, water molecules, which are polar in nature, bond to each other instead of to the CNT walls, enabling them to move together rapidly in a continuous chain. "This frictionless flow," says Olgica Bakajin, another former Livermore scientist who coled the research, "could result in a more than 20-percent reduction in energy consumption for seawater desalination and a more than 80-percent reduction for brackish water desalination."

Nanotubes Perform Well under Pressure

Reverse osmosis is a popular technique for liquid desalination. In this process, pressure is applied to a saline solution, and the liquid is pushed through a semipermeable membrane that blocks the passage of sodium chloride or other dissolved solids. Thus, the water that passes through to the other side of the membrane is purified. Because of the laws of thermodynamics, enough pressure must be applied to prevent the purified water from passing back through the membrane into the saline solution. "We must overcome the difference between the osmotic pressure of the seawater and the pure water to separate the water from the salt," says former Livermore scientist Aleksandr Noy, who also coled the development effort.

Polymer-based membranes are less permeable than those made from CNTs and thus need more pressure to obtain the desired flow rate. Unfortunately, water filtration equipment consumes more energy to produce higher pressures, which substantially increases operational costs. To increase flow rate without increasing operational pressure, manufacturers build conventional membranes as thinly as possible. However, thinner membranes are more susceptible to developing defects, such as pinholes, that reduce the membrane's efficiency. In addition, under pressure, the membrane pores constrict, further reducing the already limited flow.

The carbon nanotube development team: (from left) Francesco Fornasiero, Sangil Kim, Olgica Bakajin, and Aleksandr Noy. (Not shown: Jason Holt and Hyung Gyu Park.)

In contrast, CNT membranes have intrinsically higher permeability than conventional membranes, so they can be made thicker without sacrificing flow rate. This thicker "skin" reduces the likelihood of pinhole defects, and the membranes' overall composition makes them immune to deleterious compaction effects.

Versatile Membranes

Livermore licensed the technology to Porifera, Inc., in 2009, and the product is undergoing commercial development and testing. Its price is expected to be approximately $20 per square meter, which is comparable to the price of existing polymer-based membranes. And CNT assemblies can be built to the specifications required for replacing membrane cartridges within existing equipment, eliminating the potential for additional infrastructure costs to support the technology.

Another benefit of CNT membranes is that they can be customized for a variety of applications. At Livermore, they are being applied to several areas of research. "We're using this technology as part of an effort to develop breathable fabrics for protective clothing," says Livermore scientist Francesco Fornasiero. The fast transport capabilities of CNT membranes allow water vapor to escape through the material, unlike most protective fabrics that keep moisture in. People wearing the material can stay cooler, longer. "These fabrics would help prevent heat stress in people such as soldiers and firefighters working in hazardous, high-temperature environments," he says.

CNT membranes are also playing a role in national security and carbon sequestration research. "They could potentially overcome the limitations of gas separation membrane technologies as well as current carbon dioxide separation processes," says Sangil Kim, also formerly of Livermore. Ideally, CNT membranes could be used to separate carbon dioxide from the flue gas generated by industrial facilities such as coal-fired power plants. From helping to increase the world's clean water supply to reducing carbon emissions, CNT membranes may become essential to managing natural resources for future generations.

—Caryn Meissner

Key Words: carbon nanotube (CNT) membrane, desalination, filtration, R&D 100 Award, reclamation, reverse osmosis.

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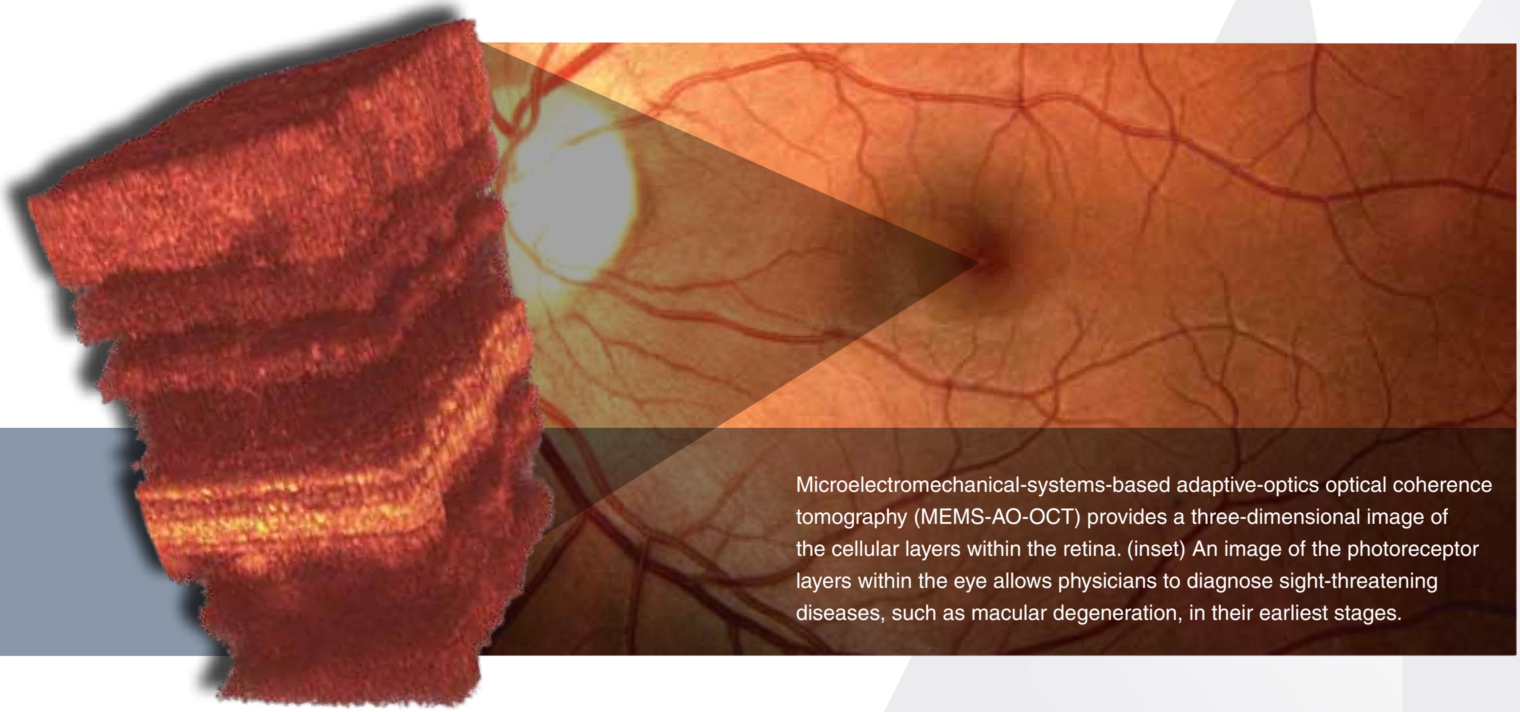

Microelectromechanical-systems-based adaptive-optics optical coherence tomography (MEMS-AO-OCT) provides a three-dimensional image of the cellular layers within the retina. (inset) An image of the photoreceptor layers within the eye allows physicians to diagnose sight-threatening diseases, such as macular degeneration, in their earliest stages.

A Look inside the Living Eye

OPHTHALMOLOGISTS and optometrists have a suite of tools for diagnosing and treating eye disease. Optical coherence tomography (OCT), for example, enables physicians to look deep inside the eye to image the subsurface tissue structure within the retina—the light-processing component of the visual system. A more advanced version of this technology has the potential to help physicians image the eye at the cellular level, allowing them to detect and monitor ocular disease at its earliest stages.

Funded by the National Eye Institute, Livermore scientists and engineers, in collaboration with the University of California at Davis, Indiana University, and Boston Micromachines Corporation in Cambridge, Massachusetts, have created an OCT system that incorporates microelectromechanical systems (MEMS) and adaptive optics (AO) to noninvasively observe and record ultrahigh-resolution, three-dimensional (3D) retinal images in real time. "Using this instrument, physicians can see the layers within a living eye in greater detail than ever before," says Diana Chen, a Livermore engineer who is one of the lead scientists on the team. Called MEMS-AO-OCT, this device allows precise in vivo visualization and characterization of all the cellular layers in the human retina. It also provides a permanent, digitized record of clinical observations for monitoring disease progression and the effectiveness of therapeutic treatments. This year, the team received an R&D 100 Award for the breakthrough technology.

Compared with other diagnostic tools that image the internal structure of the eye, such as fundus cameras and scanning laser ophthalmoscopes, MEMS-AO-OCT is the only one that can provide 3D images of multiple layers within the retina. In addition, its automated components enable the test to be run by a technician rather than a physician, reducing a procedure's overall cost.

Obtaining a Clear View

MEMS-AO-OCT incorporates an AO system similar to the one pioneered at Livermore, with initial support from the Laboratory Directed Research and Development Program, for use in large, high-powered telescopes, such as those at W. M. Keck Observatory on the big island of Hawaii. In this capacity, AO systems correct wavefront aberrations caused by atmospheric distortion, which blur our view from Earth of stars, galaxies, and other celestial objects. The same principle is applied to MEMS-AO-OCT, except that the optics correct and compensate for aberrations from ocular conditions such as myopia (nearsightedness), hyperopia (farsightedness), and astigmatism (irregular curvature of the lens). These conditions distort the light coming into the eye, causing blurred vision and also limiting the image resolution of retinal scans.

OCT systems are based on interferometry, where light from a single source is split into a sample and a reference beam.

These two separate beams travel along different paths until they ultimately reunite in a detector that measures their interference. In MEMS-AO-OCT, an ultrabroadband light is generated using a superluminescent diode, and the sample beam propagates through a series of telescopes, mirrors, and horizontal and vertical scanners before reaching the patient's eye. The light beam is focused onto the patient's retina in a raster, or uniform, pattern, creating individual "snapshots" of each layer. A wavefront sensor automatically measures the patient's optical aberrations. A MEMS deformable mirror working in conjunction with a Badal optometer and a pair of rotating cylinders then compensates for these distortions. "These components enable the device to be effective even for patients who have large refractive errors, obviating the need to fit patients with trial lenses," says Chen. The light reflected off the retina is then relayed back through the system to the detector. The reference beam, whose path length matches that of the sample beam, reflects off a pair of mirrors into the detector.

Compact afocal telescopes align the system components with the patient's pupil to achieve precise measurements. Inside the detector, a spectrometer and a charge-coupled-device camera record the sample and reference signatures. Custom computer software interprets the recorded signals and produces high-resolution, 3D, digital images. The device has a total footprint of approximately 0.5 cubic meters and can be easily placed and moved within a physician's office. In addition, its commercial components make the system a financially feasible option for practices, and its cost is competitive with existing instruments that have much lower resolution.

It's All in the Details

MEMS-AO-OCT technology could be adapted for use in other medical fields. Because biological tissues absorb and reflect light differently, the intensity and wavelength of the light source must be gauged to specific tissues to optimize image resolution. MEMS-AO-OCT can be easily adjusted to accommodate these varying light parameters, making it a valuable tool for diagnosing and treating many health conditions, including cardiovascular disease. In addition, dentists could image both hard (teeth) and soft (gums) tissues, and oncologists could identify cancer cells well before they develop into tumors. "The system could ultimately help medical professionals accurately diagnose diseases, dramatically reducing the cost of medical treatment and improving the quality of life for millions of people," says Chen.

Today, MEMS-AO-OCT is proving its capabilities as a state-of-the-art retinal imaging system. Livermore's academic partners, the University of California at Davis and Indiana University, have built and currently operate MEMS-AO-OCT as part of clinical trials. More than 100 patients with healthy and diseased eyes have been tested with the system thus far. Results have been promising, illustrating the system's ability to image minute changes in the retina that would not have been detected with standard imaging techniques. "Without adaptive optics, the resolution of a clinical OCT system is insufficient for imaging individual cellular structure," says Chen. "By incorporating adaptive optics and MEMS-based systems into OCT, we've developed a clinical instrument that is reliable, affordable, and far more effective than anything else on the market."

—Caryn Meissner

Livermore development team for MEMS-AO-OCT: (from left) Diana Chen, Scot Olivier, and Steven Jones.

Key Words: adaptive optics (AO), deformable mirror, microelectromechanical systems (MEMS), ocular disease, optical coherence tomography (OCT), R&D 100 Award, retinal imaging.

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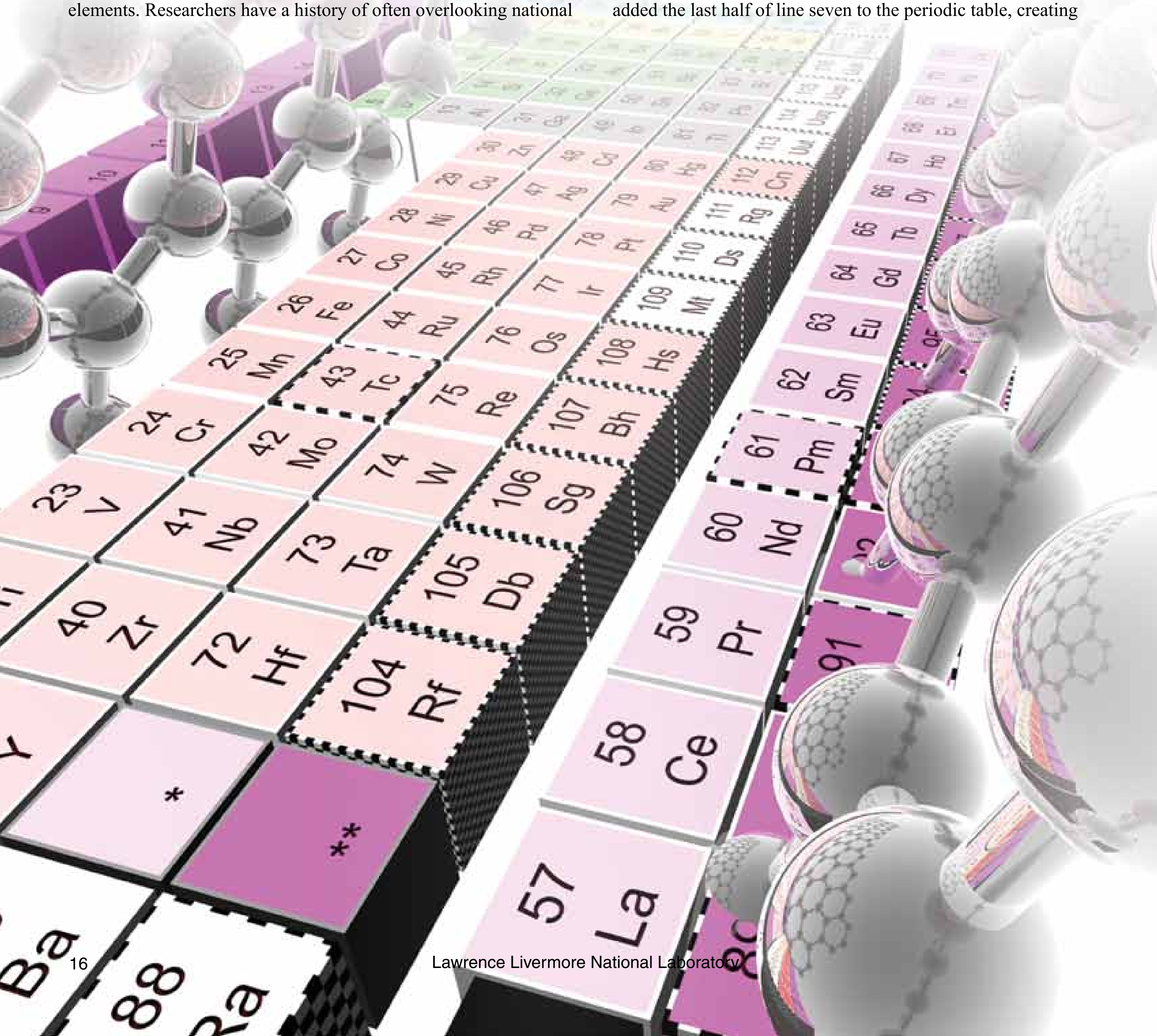
Collaboration Expands the Periodic Table, One Element at a Time

THE Laboratory's collaboration with the Joint Institute for Nuclear Research (JINR) in Dubna, Russia, began in 1989 when Livermore's Ken Hulet and Professor Georgy Flerov of JINR met at a conference and agreed to work together to create superheavy elements. Researchers have a history of often overlooking national boundaries and internecine squabbles in the interest of advancing science. But this partnership was particularly remarkable because, says Livermore's Ken Moody, "the superheavy element community then was incredibly competitive." Together, this partnership has added the last half of line seven to the periodic table, creating



elements 113 to 118. The latest element, 117, was added in early 2010. Much of this research has been supported, in part, by Livermore's Laboratory Directed Research and Development Program, beginning with a project in 1995 to examine nuclear stability in heavy nuclei.

Nuclear chemists Ron Lougheed and Moody were the first Americans to perform experiments in Dubna, spending a month at JINR in 1990. It is easy today to forget how different times were in 1990. Both the U.S. and the Soviet Union were still testing nuclear weapons. The Berlin Wall had fallen, and although the Soviet Union was wobbling, it remained intact. Some Soviet states were beginning to flex their muscles, but they would not become independent until the next year.

"The Flerov Laboratory of Nuclear Reactions [at JINR], where we did our experiments, was founded by one of the giants of Russian nuclear physics," says Moody, who is still involved in the collaboration. As it happened, Flerov died shortly after the Livermore team arrived in 1990, and he was buried with honors in the same cemetery as the Russian playwright Anton Chekhov.

Although Flerov's death put a damper on work at the institute for the duration of the Laboratory scientists' visit, Lougheed and Moody would improve an energy- and position-sensitive technology that is still being used at JINR. Development of a gas-filled mass separator to remove unwanted nuclei from desired nuclei took many years. Finally, in 1999, the creation of the heaviest known elements began in earnest.

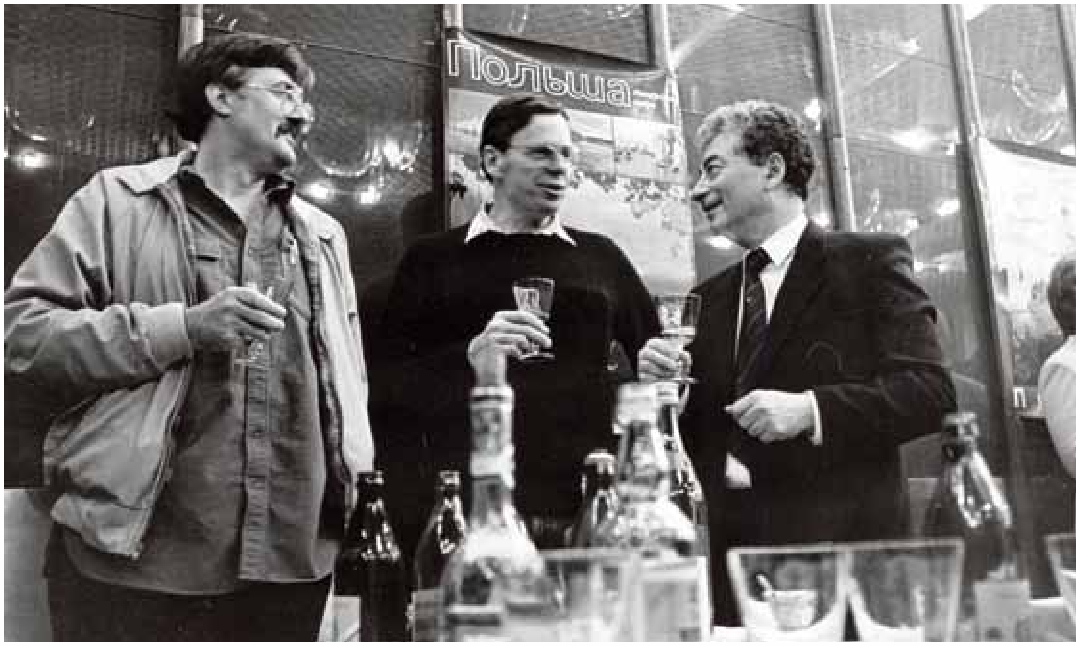
JINR, devoted solely to nuclear research of all types, is now almost as large as Lawrence Livermore with 5,500 staff members from all over the world. It houses accelerators and cyclotrons of varying energies for an array of experiments and commercial applications.

Creating New Elements

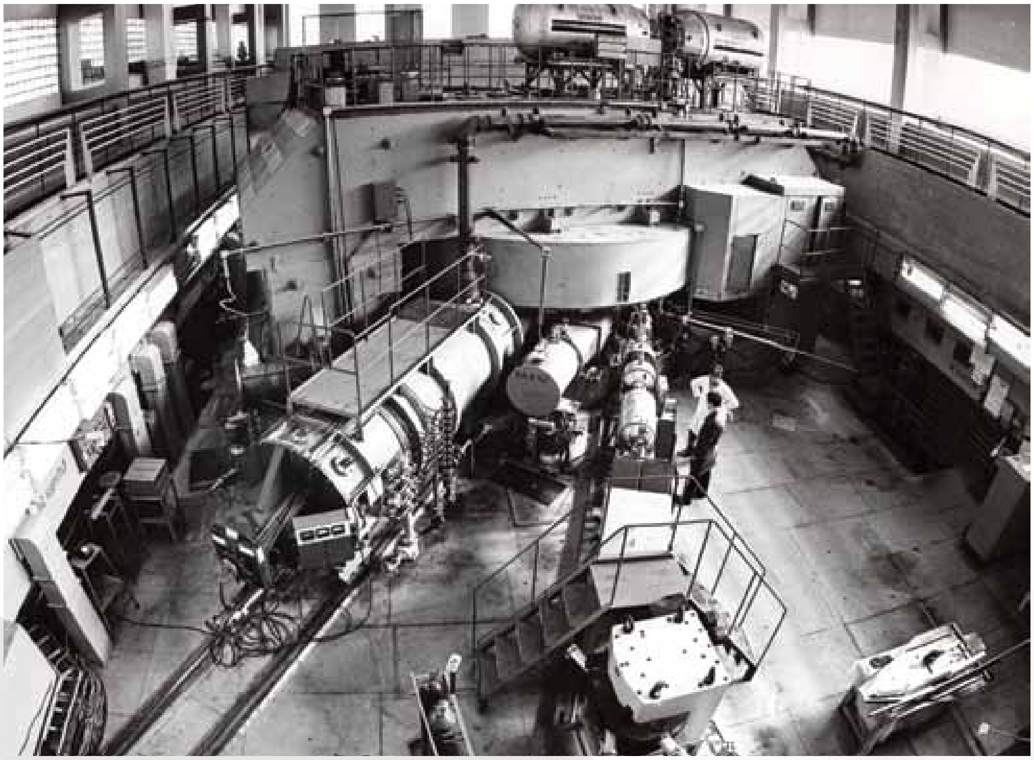
The number of an element in the periodic table—its atomic number—is defined by the quantity of protons in its nucleus. Most elements in the lower reaches of the periodic table—the gases and stable elements such as iron, copper, and calcium—have been known for hundreds of years. More unusual are elements 43 (technetium) and 61 (promethium), which were isolated and identified only with great difficulty after many years of research. Element 43, which was created in an Italian laboratory in 1937, is the lowest atomic-number element without any stable isotopes.

The highest atomic-number elements, beginning with neptunium and plutonium (elements 93 and 94), have all been created in the laboratory. Since the discovery of plutonium, scientists have fabricated 24 more elements, each one highly radioactive as well as heavier and, for the most part, with a shorter half-life than the one before it. Atoms can have multiple isotopes, depending on the number of neutrons in the atom. Element 114, for example, has an isotope called 114-289, which contains 289 nucleons in the nucleus (114 protons and 175 neutrons). Superheavy elements are those with a very high number of protons, beginning with element 104 (rutherfordium). Moody did his graduate work on superheavy elements at the University of California at Berkeley under Professor Glenn T. Seaborg (1912–1999), one of the great discoverers of heavy elements. Element 106, seaborgium, is named for him.

In the 1960s, a few physicists predicted that some superheavy elements would survive longer than any of their synthesized predecessors—a so-called "island of stability" in a sea of exceedingly short-lived elements. The very earliest estimates for the half-lives of these more stable elements were as high as billions of years. Later, computer modeling hugely reduced the



In 1990, Livermore's Ken Moody (left) and Ron Lougheed (center) joined Academician Yuri Oganessian (right), head of the Flerov Laboratory of Nuclear Reactions in Dubna, Russia, to toast the beginning of what became a 21-year collaboration to create superheavy elements.



New elements come to life, one atom at a time, in the U400 cyclotron at Flerov Laboratory of Nuclear Reactions.

anticipated half-lives to seconds or minutes before the element began to decay. Half-lives of seconds or minutes may seem brief, but some atoms have extremely short half-lives. For example, element 110 has isotopes with half-lives ranging from 100 microseconds to 1.1 milliseconds.

In vivid contrast, an atom of element 114, created by Livermore and JINR scientists in 1999, survived for 30 seconds before it began to decay—a spontaneous process that leads to the creation of another element with a lower number on the periodic table. A total of 34 minutes elapsed before the final decay product fissioned, splitting in two the surviving nucleus. These lifetimes are millions of times longer than those of previously synthesized heavy elements. The island of stability seemed tantalizingly close.

In 2000 and 2001, the collaboration used JINR's U400 cyclotron, one of the world's most powerful heavy-ion accelerators, to create element 116 in the hope of producing decay isotopes of element 114. Although the team did create several other isotopes repeatedly, some of which have since been duplicated, the long lifetime of the first atom of element 114 with 175 neutrons (114-289) has not been replicated. Similarly, element 118, created in 2006, lasted less than a millisecond before decaying.

The Challenges of Element 117

In bombarding one element with another, the number of protons in the two elements adds up to the protons in the desired new element. In element 118 experiments, californium, which has 98 protons, is fused with calcium, which has 20. The beam of calcium ions has to bombard the spinning californium target with enough force to fuse with the californium but not transfer enough energy to break apart the nucleus, or fission.

Researchers had initially skipped over element 117 because of difficulty obtaining the necessary target material, berkelium (element 97). Eventually, a two-year experimental campaign was begun at the High Flux Isotope Reactor at Oak Ridge National Laboratory with the goal of producing 22 milligrams of berkelium to discover element 117. A 250-day irradiation period was followed by 90 days of processing at Oak Ridge to separate and purify the berkelium target material. Collaborators at the Research Institute for Advanced Reactors in Dimitrovgrad, Russia, then prepared the targets. Over the next 150 days, the radioactive berkelium targets were bombarded with calcium ions in the U400 cyclotron at JINR. Finally, both Livermore and JINR analyzed the data. The entire process was driven by the 320-day half-life of the berkelium target material.

Livermore researchers (from left) John Wild (now retired), Dawn Shaughnessy, and Mark Stoyer flank a statue of Georgy Flerov, the nuclear physicist for whom the Flerov Laboratory of Nuclear Reactions is named.

The experimental campaign produced six atoms of element 117, each of which decayed to element 115, 113, and so on until fissioning. The observed decay patterns in the new isotopes continue the general trend of increasing stability for superheavy elements with increasing numbers of neutrons in the nucleus. As Lawrence Livermore Director George Miller has noted, "The discovery provides new insight into the makeup of the universe and is a testimony to the strength of science and technology at the partner institutions." However, true stability has not been found. The island of stability is near and yet still far.

Commonalities That Matter

Moody has visited Russia seven times, taking new members of the Livermore team each trip. He notes, "The country has become more westernized with every visit." By his fourth trip, Dubna had a Western-style supermarket, which was beginning to replace the individual meat, bread, and vegetable stalls. Chemist Dawn Shaughnessy, who has made four visits to JINR, noticed Coca-Cola® in an even larger supermarket during her most recent visit in September 2009. A postdoctoral fellow from Dubna, the first to come to the Laboratory, arrived this fall. According to Shaughnessy, he knows a freedom to travel and an availability of goods that surpass those experienced by his predecessors in the collaboration.

The U.S.–Russian team shares yet another commonality: the desire to continue the search for elements with properties unlike any others. Says Shaughnessy, "Each new element we discover provides more knowledge about the forces that bind nuclei and what causes them to split apart. This knowledge, in turn, helps us better understand the limits of nuclear stability and the fission process."

And what of the next elements on the periodic table? "Dubna is planning to upgrade the accelerator we use, increasing the intensity of the ion beams it produces," says Shaughnessy. "Another expected change is that the accelerator will be capable of producing beams of elements other than calcium." Fusing iron and plutonium to create element 120 will require crushing energies and a whole new ion elemental beam.

—Katie Walter

Key Words: Joint Institute for Nuclear Research (JINR), periodic table, superheavy elements.

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Students and Researchers Partner for Summer Projects

AN immigrant from China and the first college-bound member of his family, Zhi Liao puzzled over choosing a career. Career preference tests indicated he would make an ideal air traffic controller, so he headed to college with that suggestion in mind. However, it took a junior-year summer internship at Lawrence Livermore in laser optics for Liao to find an enduring vocational passion. "Until my internship, I didn't know what it is laser scientists do," says Liao. "As a summer intern, I was inspired to learn more, and I wanted to come back." He came back to do research at Livermore twice more while working toward his Ph.D. in optics, and the third time to stay, as a staff scientist at the National Ignition Facility.

Each year, the Laboratory welcomes several hundred students who spend their summer assisting Livermore scientists with research. Internship opportunities during the academic year are expanding but still less common. According to Barry Goldman, manager of many student internship programs and member of Livermore's Strategic Human Resources Management organization, the summer internship experience is most often a confirmation that students have chosen a career path and course of study that suit them. But for some, such as Liao, direct exposure to the Laboratory's robust and diverse research programs is a revelation, leading students in a direction they had never before

NIF scientist and former intern Zhi Liao (second from left) works with his summer interns. Like many Lawrence Livermore researchers, Liao sees mentoring students as a way to give back to the community and help train future scientists.

imagined. Goldman says, "One never knows what might spark or focus a student's interest."

Aspiring Auditors Choose Livermore, Too

Livermore paid and unpaid internships are primarily available in science, engineering, and technology, the Laboratory's well-known strengths. But opportunities have also broadened in recent years to include other essential disciplines that help keep a highly respected national laboratory running smoothly. Internships in areas such as law, finance, and project management introduce a broader cross section of students to the Laboratory and what it has to offer. College junior Matt Spaur recently completed his second summer in Livermore's Independent Audit and Oversight Department, reviewing expense reports, conducting interviews, and verifying payroll, among other auditing tasks. Before Spaur began his internship search, he had never heard of Lawrence Livermore nor had he any experience in auditing. Now, after two summers of intensive and rewarding on-the-job experience, the business administration major intends to pursue a career as an auditor. "To get hands-on experience in a career I am interested in is priceless," says Spaur.

Summer opportunities at the Laboratory are available for mature students at all stages of career exploration and study, from the occasional exceptional high school student to eager undergraduate students and graduate students who have finely honed their research passion. Most students are hired for the summer as paid interns through the Scholar Employment Program. This summer, just 240 students were accepted to the program, out of several thousand applicants.

A smaller but growing number of students—158 this summer—are brought in through the Academic Cooperation Program, the Laboratory's unpaid internship program. In this program, a student may receive course credit or may be sponsored by an external agency such as the Department of Homeland Security or the Department of Energy's (DOE's) National Nuclear Security Administration. These two paths to coveted Laboratory internships attract motivated students from across the nation with strong academic credentials.

Real Work, Not Busywork

Internships at Livermore offer students much more than an impressive resume entry—they give students the time and resources needed to expand or develop career-related skills and the opportunity to receive specialized training and experience from professionals in their field. Opportunities originate with researchers or staff members, who need student assistance on a project and either post the project on the Laboratory's jobs Web site (careers.llnl.gov) or indicate their interest and availability to the manager of a particular internship program. Once a student and researcher are paired by the program manager, the student assists the researcher during the summer academic break—whether in the laboratory or at a computer, working one-on-one or with team members—in accordance with project goals and criteria determined between them.

Liao now hosts his own summer students and also manages the Student Internship Program for the National Ignition Facility. As he helps match students with projects, Liao works to ensure that internships are formulated to benefit both parties. "We need to make sure that the projects are appropriate for both the mentor and student," says Liao. "A balance is required to keep the students interested and productive."

Attention to the learning component of internships makes summers at the Laboratory a far cry from the coffee making and paper shuffling of a stereotypical internship. Here, interns make real contributions to research projects. Klint Rose, engineer and winner of a DOE 2009 Outstanding Mentor Award, says, "I put my students right on the critical path. They do real projects with real impacts, and the result is that they appreciate making a contribution." Rose's interns have made essential presentations and conducted demonstrations for high-profile audiences. As a former Livermore intern himself, he understands what students are hoping for from an internship. "My student experience helps me know what is reasonable as a summer project, what will help a student grow and not just be busywork," says Rose.

Learning Experience for Mentors and Students Alike

John Knezovich, also a former summer student, is director of Strategic University Relations, the Laboratory's point of contact for all DOE summer programs. According to Knezovich, what catches students by surprise is how researchers dispense with titles and hierarchy and treat them as team members and colleagues. "Students and researchers get their hands dirty together, solving problems," says Knezovich. "Students appreciate and see the value of interdisciplinary teams, which is the hallmark of what we do." Not only is the interdisciplinary, egalitarian work environment a refreshing contrast for many students familiar with the more rigid disciplines and traditional hierarchies of a university setting, but it also introduces students to founder Ernest O. Lawrence's vision of team science—solving seemingly intractable problems using all available tools and resources.

Solid career experience, real responsibilities, and treatment as a peer are what students value most about a Livermore experience, according to exit surveys conducted by Goldman. These features attract and retain stellar students. A full quarter of this summer's interns are students who have returned to the Laboratory to continue their research or explore a new topic. All undergraduate interns are encouraged to submit abstracts and papers to DOE's *Journal of Undergraduate Research* at the end of the summer—for many, their first opportunity to publish research. Sometimes, discoveries during summer internships have even led to unique opportunities for students to coauthor papers or copresent posters at a science conference. Physicist Don Correll of the Physical and Life Sciences Directorate has been involved with student programs in various capacities for many years. He notes, “A summer at the Lab raises the level of scientific knowledge for students. They experience the highest caliber of research. Individual mentors are the people who make all of this possible.”

For mentors, the experience has its own rewards. Many mentors are former summer students themselves who view mentoring as a way to give others the same opportunity. Both Rose and Liao mentor several students each year. Interns naturally bring extra help to short-handed projects, but they also provide a fresh perspective, someone who may question a process and cause researchers to rethink their assumptions or methods. Working with students also gives mentors a chance to exercise their teaching and managerial skills. According to Goldman, “Mentoring helps Livermore researchers retain their connection to academia, to see what is being taught and which technologies are being used for research.” Select mentors gain broader recognition for their efforts through the student-nominated Outstanding Mentor Award Program administered by DOE’s Office of Science.

Long-Term Connections Start with Internships

Hosting outstanding student interns is a win–win situation. Goldman sees summer programs as an opportunity to build a long-term relationship with students and establish Livermore in their minds as a leading scientific laboratory. One Academic Cooperation Program that he manages, the Military Academic Research Associate (MARA) Program, brings midshipmen, cadets, and faculty in U.S. military branches to the Laboratory for a month—only one-third the length of most internships—to experience Livermore’s research offerings. MARA is a model program for the National Nuclear Security Administration, which is looking to expand its national laboratory–military collaborations. The program enables academy instructors to expand and build on their teaching curriculum. In addition, it gives future military officers familiarity with and respect for the Laboratory and how its research contributes to the Department of Defense.

According to Goldman, the summer programs also function as a “pipeline” to attract promising students to a career at Livermore. Many Laboratory researchers and administrators are former summer students, including Director Emeritus Bruce Tarter. While not all of the students will return to work at Livermore after graduating, other long-term benefits are seen in bringing in summer students. Says Goldman, “If students go on to work in industry, the opportunity may arise for further collaboration. If they go on to academia, they may send students to Livermore as well as have a desire to collaborate.” Past internships have led to fruitful professional partnerships between former students and Laboratory researchers.

Events Spur Friendship and Networking

Goldman has been managing various Livermore internship programs for 12 years. One of his most enduring contributions is the creation of the Institutional Education Committee (IEC), which includes representatives from departments across the Laboratory. The committee plans a broad range of summer activities to engage students of various ages and interests. Events this summer included tours of the Joint Genome Institute in Walnut Creek, California, and Livermore’s High Explosives Applications Facility; social activities such as barbecues and an ever-popular rafting excursion; research talks and panel discussions by scientists; and seminars on the practice of science, including understanding patents and how to write an abstract. These events are optional and open to all Laboratory students.

Rose chose to spend his summer internships working mostly at his desk or in the lab, with limited social interaction, he admits with a laugh. He has come to value the student activities and now encourages his students to take full advantage of the offerings. Not only are the activities an opportunity to meet students and researchers with whom they may later interact, but the events also expose students to the breadth of research performed at the Laboratory. Students can be surprised to discover that some

Livermore summer interns from the Military Academic Research Associate Program, ROTC, and other student programs pose at Pony Tracks, a collection of tanks, in nearby Portola Valley, California. Occasional student field trips to relevant science, engineering, and national security destinations supplement their daily internship tasks.

A student discusses her summer research results with Livermore physicist Don Correll at a student poster symposium. Held each August, the event is modeled on professional scientific poster sessions and offers students presentation experience and networking opportunities.

long-time employees have had multiple careers while at the Laboratory because of the diversity of research offerings.

A summer highlight is the student poster symposium, held every August and attended by many Livermore researchers. This event is modeled after the poster sessions at a professional scientific meeting, and all summer students are invited to participate. Correll, one of the creators of the student poster session, is pleased with the results. He says, "When Lab scientists come, they see what they'd find at a professional session. The students produce an excellent set of posters." Many mentors encourage students to start thinking about their posters as soon as they arrive. According to Correll, the poster work forces students to consider not only how to present technical content but also how to create a pleasing and instructive visual presentation—useful professional skills in most any field. The poster session offers a satisfying conclusion to a summer of career immersion and hands-on experience.

The Laboratory's enduring relationship with the University of California has imbued its staff with strong support and respect for education and career preparation opportunities. Fewer high schools offer career counseling services, and yet many more students attend college, many of whom are the first in their family to do so. The nation has a strong need for institutions to provide opportunities that guide students toward a good career match and encourage outstanding students to consider graduate-level education. The Laboratory's internships are a valuable resource for inspiring students and help them steer a confident course toward their future career.

Laboratory management strongly supports and values the summer student programs and what they offer both the Laboratory and the student community. "Summer students give as much or more to the Laboratory as they receive from us," says Laboratory Director George Miller. "They bring a special curiosity and enthusiasm for learning. They often energize project teams and rekindle our thirst for knowledge, reminding us of the reasons we chose careers at a national laboratory." Whether summer students continue on to graduate school or enter the working world, exposure to the Laboratory's innovative, multidisciplinary approach to tackling tough projects provides practical experience that they can draw on time and again.

—Rose Hansen

Key Words: Academic Cooperation Program, Institutional Education Committee, Military Academic Research Associate (MARA) Program, Outstanding Mentor Award, Scholar Employment Program, Student Internship Program.

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Patents and Awards

In this section, we list recent patents issued to and awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory.

Patents

Magnetohydrodynamic Pump with a System for Promoting Flow of Fluid in One Direction

Asuncion V. Lemoff, Abraham P. Lee
U.S. Patent 7,753,656 B2
July 13, 2010
This magnetohydrodynamic (MHD) pump has a microfluidic channel for channeling fluid, an MHD electrode–magnet system connected to the channel, and a system for promoting fluid flow through the channel in one direction. The pump can be used by the medical and biotechnology industries in blood-cell-separation equipment and biochemical assays and for chemical synthesis, genetic analysis, drug screening, an array of antigen–antibody reactions, drug testing, medical and biological diagnostics, and combinatorial chemistry. The pump can also be used in electrochromatogaphy, surface micromachining, laser ablation, ink-jet printers, and mechanical micromilling.

Preparation of Membranes Using Solvent-Less Vapor Deposition Followed by In-Situ Polymerization

Kevin C. O'Brien, Stephan A. Letts, Christopher M. Spadaccini, Jeffrey C. Morse, Steven R. Buckley, Larry E. Fischer, Keith B. Wilson
U.S. Patent 7,754,281 B2
July 13, 2010
In this system for fabricating a composite membrane from a membrane substrate, solventless vapor deposition is followed by in situ polymerization. First and second monomers are mixed in a deposition chamber and are then deposited via a solventless vapor onto the membrane substrate in the chamber. The membrane substrate and the monomer mixture are heated to produce in situ polymerization and provide the composite membrane.

Real-Time Multiplicity Counter

Mark S. Rowland, Raymond A. Alvarez
U.S. Patent 7,755,015 B2
July 13, 2010
A neutron multidetector array feeds pulses in parallel to individual inputs tied to individual bits in a digital word. Data are collected by loading a word at the individual bit level in parallel. The word is read at regular intervals, all bits simultaneously, to minimize latency. The electronics then pass the word to several storage locations for processing, thereby removing the front-end problem of pulse pileup.

Absolute Nuclear Material Assay

Manoj K. Prasad, Neal J. Snyderman, Mark S. Rowland
U.S. Patent 7,756,237 B2
July 13, 2010
This method produces an absolute nuclear material assay by counting neutrons from an unknown source and comparing the measured count distributions to a model. One setup uses a random sampling of analytically computed fission chain distributions to generate a continuous time-evolving sequence of event counts by spreading the fission chain distribution in time.

Awards

Tammy Ma, a Lawrence Scholar and postdoctoral researcher in the National Ignition Facility (NIF) and Photon Science Principal Directorate, has received the **2010 Mechanical and Aerospace Engineering Award for Outstanding Graduate Student** from the **University of California at San Diego** (UCSD). Her doctoral thesis, "Electron Generation and Transport in Intense Relativistic Laser–Plasma Interactions Relevant to Fast Ignition ICF," was completed under the supervision of San Diego Professor Farhat Beg and NIF researcher Andrew MacPhee. Her research was closely connected to fast ignition and high-energy-density science.

Ma started as a Lawrence Scholar in 2008, but that was not her first time at the Laboratory. In 2001, while a student at Mission San Jose High School in Fremont, California, she worked as a summer intern in the Laboratory's Institute for Geophysics and Planetary Physics. In a letter informing her of the award, Department Chair Sutanu Sarkar wrote, "Graduate students play a pivotal role in our department and at UCSD. You have been very productive in research related to electron transport and laser matter interactions, as evidenced through publication in reputed journals."

Physicist **Dmitri Ryutov** received the **2010 Distinguished Career Award** from **Fusion Power Associates** for his contributions to fusion research. The award recognizes Ryutov's body of contributions to physics as well as individual projects and research achievements. He has been involved in different approaches to and aspects of fusion energy from NIF to tokamak magnetic fusion reactors and the Z-pinch machine developed by Sandia National Laboratories. Ryutov is also a member of one of Livermore's 2010 R&D 100 Award–winning teams. (See the highlight on p. 8.)

His passion for taking on physics problems in diverse research areas has been a driving force of his career. Ryutov is a theoretical physicist who thrives in the Laboratory's multidisciplinary team science culture. His first contact with Livermore was in the late 1970s through a Soviet–American research collaboration on magnetic mirrors, when he was a scientist at the Budker Institute of Nuclear Physics in Siberia.

Bryan Balazs of the Weapons and Complex Integration Principal Directorate was elected **fellow** of the **American Chemical Society** (ACS). Balazs is an associate program leader in B Program, which receives its funding through a complicated set of funding streams, and each source has its own oversight and reporting requirements. Balazs's job entails, as he describes it, "untangling the financial knots" as well as dealing with budgetary, planning, and performance metrics.

He joined the Laboratory in 1992 as a postdoctoral fellow, developing sensors to measure effluent streams and oxygen under high temperatures such as in automobile engines. Balazs transitioned into the weapons program in 1998, studying materials issues associated with nuclear weapons, developing advanced diagnostics for stockpile measurements, and contributing to the development of scientific lifetime models based on aging trends observed in the stockpile. He has been active in ACS nearly his entire tenure at the Laboratory.

Ed Moses, principal associate director of the NIF and Photon Science Principal Directorate, is a regional winner of a **Jefferson Award** for his education outreach in the community. Moses routinely volunteers his time to engage with and lecture to students and the general public on physics, lasers, and photon science as well as NIF, the world's largest laser. The Jefferson Awards were cofounded in 1972 by Jacqueline Kennedy Onassis to honor volunteerism and community outreach throughout the U.S. The awards, named for Thomas Jefferson, are presented on two levels: national and regional.

The **Federal Laboratory Consortium's Far West Region** competition awarded Lawrence Livermore two honors. Laboratory employees **John Dzenitis**, **Vincent Riot**, and **Catherine Elizondo** received an **Outstanding Partnership Award** for their partnering efforts with the Monterey Bay Aquarium Research Institute and Spyglass Biosecurity, Inc., in the development, transfer, and licensing of a real-time environmental sampler for conducting biological analyses. Laboratory scientists **Tom Slezak**, **Crystal Jaing**, **Shea Gardner**, and **Kevin McLoughlin** received the **Outstanding Technology Development Award** for their work in developing a microarray that can detect more than 2,000 viruses and 900 bacteria in 24 hours.

Physicist **Prav Patel** received the **2010 Excellence in Fusion Engineering Award** from **Fusion Power Associates** for his work in relativistic laser–plasma interaction and leadership in developing the fast-ignition concept for inertial confinement fusion. "It really represents the accomplishments of the entire fast-ignition team here at Livermore," says Patel.

Patel jumped right into the field of relativistic laser–plasma interaction and fast ignition when he arrived at the Laboratory 11 years ago. As a postdoctoral researcher, he started his work in high-intensity, short-pulse lasers at Livermore's Jupiter Laser Facility using first the 100-terawatt Callisto laser and then the petawatt-class Titan laser.

The Excellence in Fusion Engineering Award was established in 1987 to recognize persons in the relatively early part of their careers who have shown both technical accomplishments and potential to become exceptionally influential leaders in the fusion field.

U.S. Government Printing Office: 2010/670-075-71023

Coming Next Issue

Carbon Dating Advances Climate Science

The Center for Accelerator Mass Spectrometry has become an essential resource for helping scientists to understand climate change.

Also in December

• Sophisticated diagnostic equipment installed at the National Ignition Facility will measure the key physical processes occurring in high-energy-density experiments.

• A new device developed at Livermore can detect and identify thousands of viruses and bacteria simultaneously in a day.

• The Laboratory's technique for sequestering carbon dioxide underground shows promise for mitigating the effects of this greenhouse gas while producing freshwater.

Science & Technology Review
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